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Evaluation of the reproductive potential of *Clania variegata* (Lepidoptera: Psychidae), an serious garden defoliator, on four host plants

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Abstract: 【Aim】 *Clania variegata* (Lepidoptera: Psychidae) is a major defoliating pest on several tree species worldwide. In order to control this pest through wise arrangement of plant species in gardens and parks, we evaluated the reproductive potential of *C. variegata* on four host plants (*Platanus acerifolia*, *Osmanthus fragrans*, *Albizia julibrissin* and *Amygdalus persica*). 【Methods】 The duration of egg, larval and pupal stages, survival rate, adult longevity, oviposition period of female adult and daily number of eggs laid per female of *C. variegata* on *P. acerifolia*, *O. fragrans*, *A. julibrissin*, and *A. persica* were recorded in a natural open environment, in Shaanxi Province, northwestern China, from July 15, 2018 to June 21, 2019. The data of developmental duration, survival rate, adult longevity, and female fecundity were analyzed by the age-stage, two-sex life table theory, using TWOSEX-MSChart software. 【Results】 The developmental duration and adult longevity of *C. variegata* were significantly affected by the host plant species. The duration of the 2nd, 3rd, 4th and 5th larval instars of *C. variegata* on *O. fragrans* was significantly longer than that on the other host plants. *C. variegata* adult females exhibited significantly greater longevity on *A. persica* (11.47 d) than on *O. fragrans* (10.26 d). The oviposition period of *C. variegata* on *O. fragrans* (7.04 d) was significantly shorter than those on *P. acerifolia* (7.52 d), *A. julibrissin* (7.59 d), and *A. persica* (8.11 d). The net reproductive rate (R_0) of *C. variegata* on *P. acerifolia* (2 015.70 eggs) was significantly higher than those on *O. fragrans* (1 419.12 eggs), *A. persica* (1 289.66 eggs), and *A. julibrissin* (976.67 eggs). The intrinsic rate of increase (r) of *C. variegata* on *P. acerifolia* (0.02523/d) was significantly greater than those on *O. fragrans* (0.02377/d), *A. julibrissin* (0.02304/d), and *A. persica* (0.02194/d). 【Conclusion】 The reproductive potential of *C. variegata* on *P. acerifolia* was significantly greater than those on *O. fragrans*, *A. julibrissin*, and *A. persica*. Alternate planting of *O. fragrans*, *A. julibrissin*, and *A. persica* might help reduce the damage of *C. variegata* to non-preferable plants.

Key words: *Clania variegata*; *Platanus acerifolia*; *Osmanthus fragrans*; *Albizia julibrissin*; *Amygdalus persica*; reproductive potential; fecundity

1 INTRODUCTION

Clania variegata (Lepidoptera: Psychidae) is a major defoliator pest, damaging several landscape and fruit trees. Its host range includes, but is not limited to, sycamore (*Platanus orientalis*), peach (*Amygdalus persica*), sweet-scented osmanthus (*Osmanthus fragrans*), silk tree (*Albizia julibrissin*), tea (*Camellia sinensis*), mulberry (*Morus alba*), apple (*Malus pumila*), pear (*Pyrus* spp.), plum (*Prunus salicina*), apricot (*Armeniaca vulgaris*), grape (*Vitis vinifera*), chestnut (*Castanea mollissima*), walnut (*Juglans regia*), persimmon (*Diospyros kaki*), loquat (*Eriobotrya japonica*), citrus (*Citrus reticulata*), longan (*Dimocarpus longgana*), paulownia (*Paulownia fortunei*), robinia (*Robinia pseudoacacia*), elm (*Ulmus pumila*), poplar (*Populus tomentosa*), and willow (*Salix babylonica*) (Qiao *et al*., 1994; Ju *et al*., 2004; Zhang, 2010). This pest is widely distributed in China, North Korea, Japan, Vietnam, Laos, Thailand, India, Sri Lanka, Malaysia, Indonesia and Australia (Zhang, 2010). *C. variegata* has been documented in most provinces in China, including Henan, Hebei, Shaanxi, Shanxi, Tibet,

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Zhejiang, Jiangsu, and Shandong (Qiao *et al.*, 1994), and Changchun City of Jilin Province representing the northernmost collection point (Zhang, 2010).

Previous studies have assessed the extent of damage (Zhang, 2010), host range (Chen and Fan, 2016), effective accumulated temperature (Tian *et al.*, 1993), occurrence (Yang *et al.*, 1997), biological features (Wan and Wan, 1983), sex pheromones (Zhao, 1988), and antenna substructures (Zhao *et al.*, 1986) of *C. variegata*, for developing chemical and biological control measures against this pest of landscape plants (Ju *et al.*, 2004). However, studies on the biological and ecological characteristics of *C. variegata* underlying its precise population dynamics in the natural environment are scarce. Therefore, in this study we evaluated the developmental duration, survival rate, adult longevity, fecundity, and intrinsic rate of increase (r) of *C. variegata* on four host plants, *Platanus acerifolia*, *Osmanthus fragrans*, *Albizia julibrissin*, and *Amygdalus persica*, in the natural environment, in Shaanxi Province, northwestern China, from July 15, 2018 to June 21, 2019. Our results are expected to contribute to the design and management of gardens and parks, by reducing alternative host plants, for effective control of this pest.

2 MATERIALS AND METHODS

2.1 Insect rearing

C. variegata individuals were collected initially from the campus of Northwest A&F University, Yangling, Shaanxi, China, in 2017, and then reared in greenhouses of College of Landscape Architecture and Art of the university. The larvae were then transferred onto 3-year-old *P. acerifolia*, *O. fragrans*, *A. julibrissin*, and *A. persica* plants, at 28℃, 70% relative humidity (RH) under a photoperiod of 14L∶10D, until pupation. The pupae were maintained on trees until emergence. Adult males searched for adult females at night for mating. Adult *C. variegata* females laid eggs at the opening of the protective bag. The eggs were collected daily and placed on wet black papers to maintain a constant humidity (70%) until hatching.

2.2 Life table analysis

Fifty eggs (72 h-old) were selected randomly from the colony consisting of an equal ratio (1∶1) of females and males, from each of the four tree species for life table assessment. These egg clusters were then placed carefully on a piece of wet black paper (5 cm × 5 cm) to maintain humidity. After hatching, each larva was transferred onto a new 3-year-old tree, to feed on the 5 – 10-day-old leaves. Each tree was maintained in a nylon bag (60 meshes: 40 cm × 40 cm × 100 cm). Larval development was monitored and recorded until adult emergence or death at any larval or pupal stage. The emerged female and male adults were paired. If sufficient adult males were not available, other adult males on the same plant were used to ensure that each adult female could mate once. Then 27, 23, 17, and 19 adult pairs of *C. variegata* were introduced onto *P. acerifolia*, *O. fragrans*, *A. julibrissin*, and *A. persica*, respectively. Eggs were collected daily from the female protective bags. Adult longevity and fecundity (number of eggs laid per female) were also recorded daily. All eggs, larvae, pupae, and adults were maintained in an open garden environment (34°16′56.24″N, 108°4′27.95″E) at Northwest A&F University, Yangling, Shaanxi. The experiment commenced on July 15, 2018 and concluded on June 21, 2019.

2.3 Data analysis

The raw data for each *C. variegata* individual, including developmental duration, survival rate, adult longevity, and female fecundity, were analyzed by the age-stage, two-sex life table theory, using TWOSEX-MSChart software (Chi and Liu, 1985; Chi, 1988, 2018). The age-stage-specific survival rate (s_{xj}), age-specific survival rate (l_x), age-stage-specific fecundity (f_{xj}), age-specific fecundity (m_x), net reproductive rate (R_0), intrinsic rate of increase (r), finite rate of increase (λ), age-stage life expectancy (e_{xj}), reproductive value (v_{xj}), and mean generation time (T) were calculated, following Chi and Liu (1985). Here, x and j indicate the age and stage, respectively (Chi, 2018).

3 RESULTS

3.1 Age-stage, two-sex life table of *C. variegata* on four host plants

The age-stage-specific survival rate (s_{xj}) indicated the precise survival rate of the tested population at age x and stage j. Due to the different developmental rates of individuals of *C. variegata*, the s_{xj} value exhibited partial overlaps (Fig. 1).

The mean developmental duration, adult longevity, and female fecundity of *C. variegata* were shown in Table 1. The egg duration, entire larval duration, and pupal duration of *C. variegata* on the four host plants were significantly different. Adult females exhibited significantly greater longevity on *A. persica* (11.47 d) than on *O. fragrans* (10.26 d). Adult males exhibited considerably greater longevity on *P. acerifolia* (2.94 d) than on *A. persica*

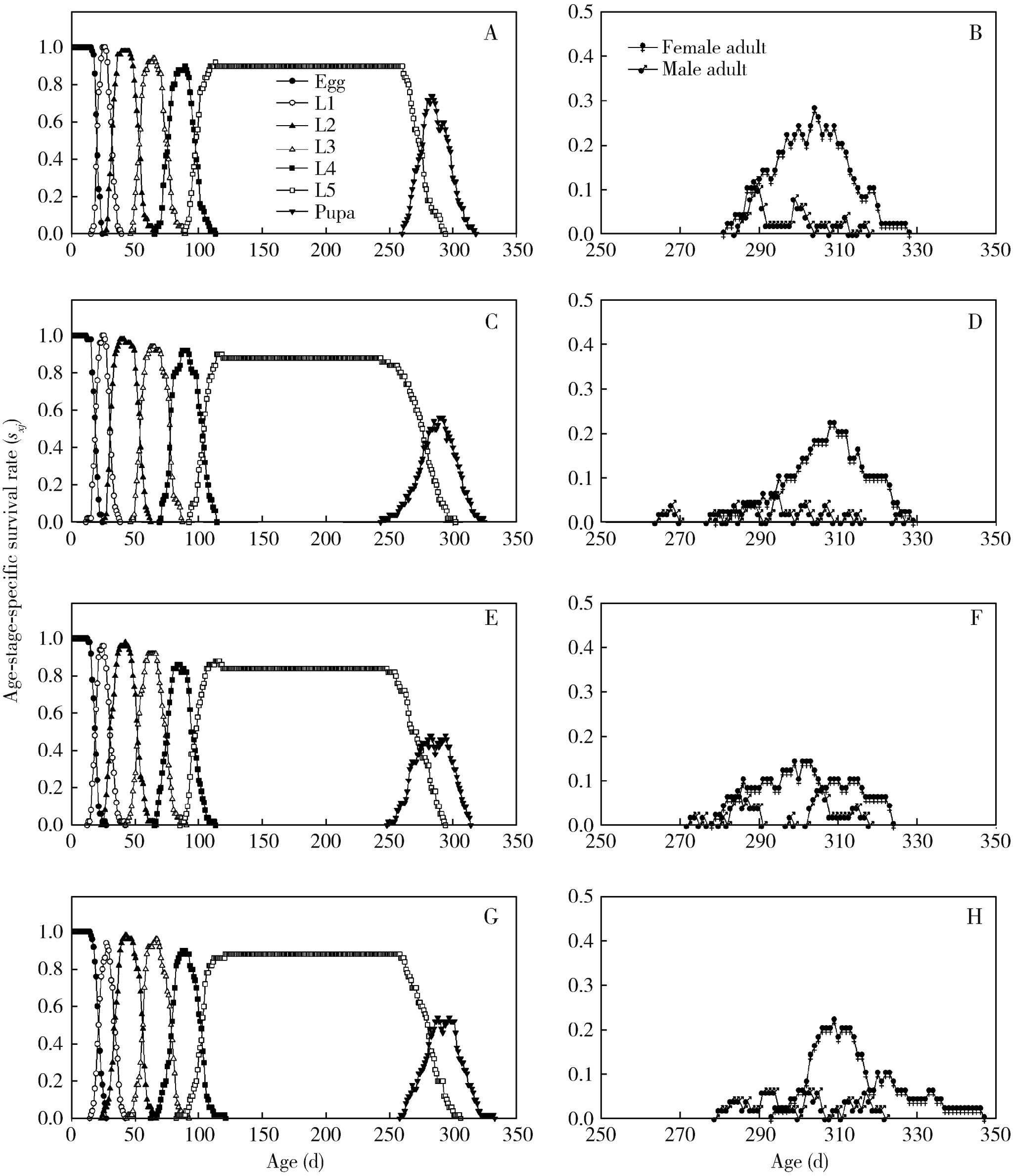

Fig. 1 Age-stage-specific survival rates (s_{xj}) of *Clania variegata* on *Platanus acerifolia* (A and B), *Osmanthus fragrans* (C and D), *Albizia julibrissin* (E and F), and *Amygdalus persica* (G and H)

L1 – L5: 1st – 5th instar larva, respectively.

Table 1 Development and fecundity of *Clania variegata* on *Platanus acerifolia*, *Osmanthus fragrans*, *Albizia julibrissin*, and *Amygdalus persica*

Parameters	*P. acerifolia*		*O. fragrans*		*A. julibrissin*		*A. persica*	
	n	Mean ± *SE*	*n*	Mean ± *SE*	*n*	Mean ± *SE*	*n*	Mean ± *SE*
Egg duration (d)	50	20.36 ± 0.27 b	50	18.80 ± 0.33 c	50	18.76 ± 0.37 c	50	21.54 ± 0.42 a
1st larval instar duration (d)	50	11.70 ± 0.26 c	49	12.04 ± 0.23 abc	49	12.39 ± 0.32 ab	50	12.46 ± 0.32 a
2nd larval instar duration (d)	48	21.58 ± 0.32 b	48	23.25 ± 0.31 a	48	21.52 ± 0.34 b	49	21.59 ± 0.30 b
3rd larval instar duration (d)	46	22.13 ± 0.33 b	46	23.54 ± 0.33 a	46	21.98 ± 0.36 b	47	22.34 ± 0.41 b
4th larval instar duration (d)	46	22.52 ± 0.37 c	45	25.64 ± 0.46 a	44	22.66 ± 0.38 c	45	23.76 ± 0.41 b
5th larval instar duration (d)	45	176.59 ± 1.14 b	44	173.41 ± 1.70 c	42	176.55 ± 1.19 b	44	179.14 ± 1.39 a
Pupal duration (d)	45	22.44 ± 0.29 a	44	21.61 ± 0.36 b	41	21.68 ± 0.31 b	43	21.81 ± 0.35 ab
Pre-adult period (d)	45	305.42 ± 1.48 ab	44	305.07 ± 2.21 ab	41	301.37 ± 2.04 b	43	309.81 ± 2.25 a
Female adult longevity (d)	27	11.07 ± 0.56 ab	23	10.26 ± 0.50 b	17	11.29 ± 0.72 ab	19	11.47 ± 0.66 a
Male adult longevity (d)	18	2.94 ± 0.27 a	21	2.14 ± 0.20 c	24	2.21 ± 0.20 bc	23	2.62 ± 0.21 b
Oviposition period (d)	27	7.52 ± 0.29 a	23	7.04 ± 0.22 b	17	7.59 ± 0.36 a	19	8.11 ± 0.37 a
Fecundity (number of eggs laid per female per day)	27	3 732.78 ± 111.13 a	23	3 085.04 ± 83.49 c	17	2 872.53 ± 130.81 d	19	3 393.84 ± 125.79 b

Different letters following the data in the same row indicate significant difference ($P < 0.05$, paired bootstrap test).

(2.62 d), *A. julibrissin* (2.21 d), and *O. fragrans* (2.14 d).

3.2 Fecundity of *C. variegata* on four host plants

The oviposition period of *C. variegata* on *P. acerifolia*, *O. fragrans*, *A. julibrissin*, and *A. persica* was 7.52, 7.04, 7.59, and 8.11 d, respectively. The oviposition period of *C. variegata* on *O. fragrans* was significantly shorter than those on *P. acerifolia*, *A. julibrissin*, and *A. persica*. The fecundity of *C. variegata* decreased significantly, depending on the host plant species, in the order of: *P. acerifolia* (3 732.78 eggs laid per female per day) > *A. persica* (3 393.84 eggs laid per female per day) > *O. fragrans* (3 085.04 eggs laid per female per day) > *A. julibrissin* (2 872.53 eggs laid per female per day).

The age-specific survival rate (l_x) represents the probability that a laid egg will survive to age x and was calculated by pooling all individuals of both sexes in the present study. The l_x of *C. variegata* on *P. acerifolia*, *O. fragrans*, *A. julibrissin*, and *A. persica* decreased gradually with increasing age (Fig. 2).

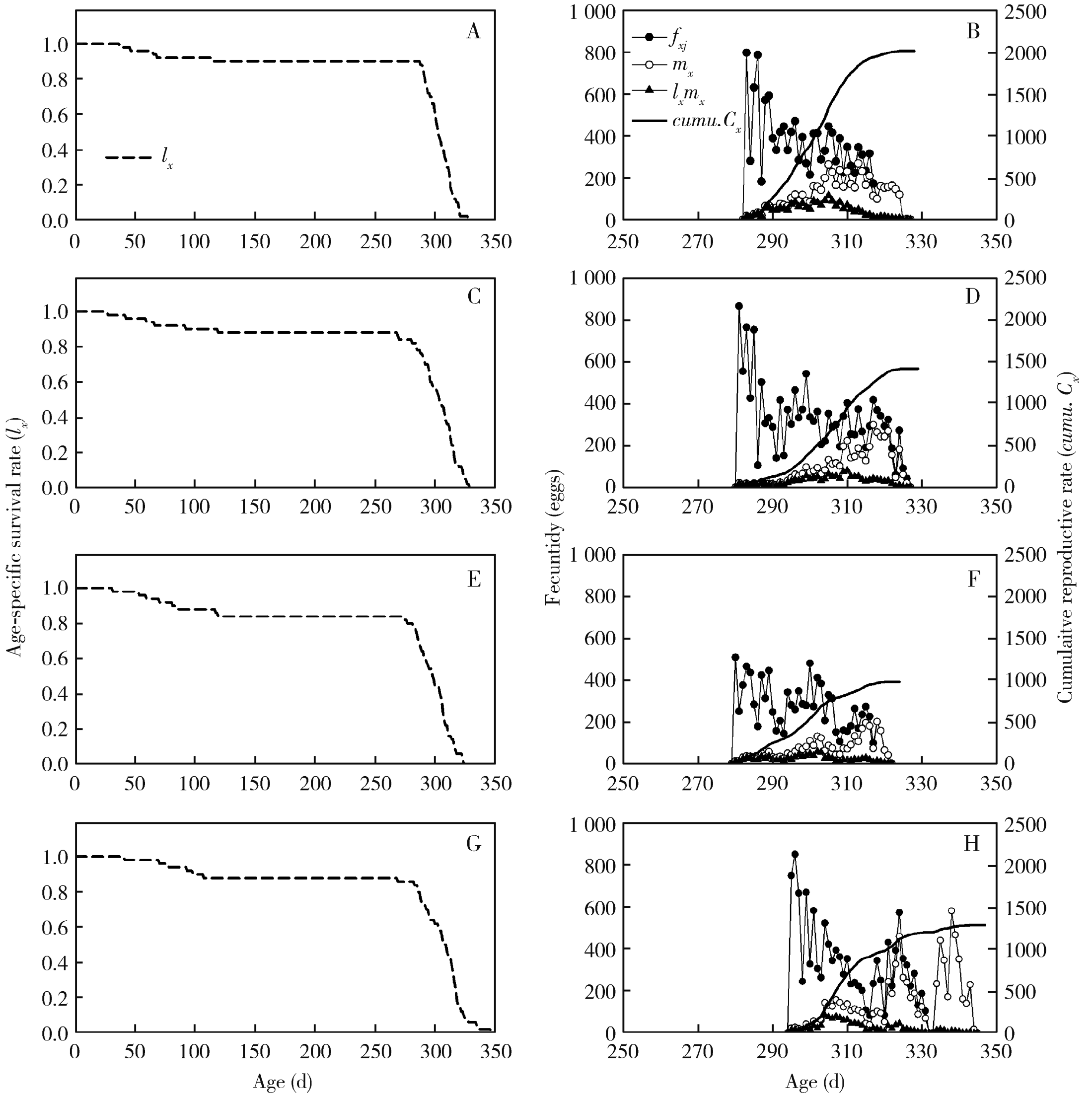

Fig. 2 Age-specific survival rates (l_x), age-stage-specific fecundity (f_{x8}), age-specific fecundity (m_x), age-specific net fecundity (l_xm_x) and cumulative reproductive rate (*cumu.* C_x) of *Clania variegata* on *Platanus acerifolia* (A and B), *Osmanthus fragrans* (C and D), *Albizia julibrissin* (E and F) and *Amygdalus persica* (G and H)

The age-stage-specific fecundity (f_{x8}, adult as the 5th stage life) of *C. variegata* on *P. acerifolia*, *O. fragrans*, *A. julibrissin*, and *A. persica* was 797.00, 865.00, 507.00, and 853.00 eggs at 283, 281, 280, and 296 d post infestation, respectively. The age-specific fecundity (m_x) on these four host plants peaked at 313, 317, 318, and 338 d post infestation, with the values of 268.89, 297.43, 200.33, and 583.00 eggs, respectively. The age-specific net fecundity ($l_x m_x$) on these four host plants peaked at 305, 309, 302, and 304 d post infestation, with the values of 116.2, 74.56, 57.26, and 83.92 eggs, respectively.

The intrinsic rate of increase (r) of *C. variegata* on *P. acerifolia*, *O. fragrans*, *A. julibrissin*, and *A. persica* was 0.02523, 0.02377, 0.02304, and 0.02194/d, respectively. The intrinsic rate of increase of *C. variegata* on *P. acerifolia* was significantly higher than those on the other host plants. The finite rate of increase (λ) exhibited the same trend. The net reproductive rate (R_0) of *C. variegata* on *P. acerifolia*, *O. fragrans*, *A. julibrissin*, and *A. persica* was 2 015.70, 1 419.12, 976.67, and 1 289.66 eggs, respectively. The R_0 value of *C. variegata* on *P. acerifolia* was significantly higher than those on *O. fragrans*, *A. julibrissin*, and *A. persica*. The mean generation time (T) on *A. persica* (312.24 d) was significantly higher than those on *O. fragrans* (305.40 d), *P. acerifolia* (301.54 d), and *A. julibrissin* (298.74 d) (Table 2).

Table 2 Population parameters of *Clania variegata* on *Platanus acerifolia*, *Osmanthus fragrans*, *Albizia julibrissin* and *Amygdalus persica*

Parameters	*P. acerifolia*	*O. fragrans*	*A. julibrissin*	*A. persica*
Intrinsic rate of increase r (d^{-1})	0.02523 ± 0.00049 a	0.02377 ± 0.00056 b	0.02304 ± 0.00072 bc	0.02194 ± 0.00064 c
Finite rate of increase λ (d^{-1})	1.02555 ± 0.00050 a	1.02405 ± 0.00057 b	1.02331 ± 0.00073 bc	1.02220 ± 0.00065 c
Net reproductive rate R_0 (eggs)	2 015.70 ± 273.80 a	1 419.12 ± 218.36 b	976.66 ± 195.87 c	1 289.66 ± 239.11 bc
Mean generation time T (d)	301.54 ± 1.68 bc	305.40 ± 2.27 b	298.74 ± 2.44 c	312.24 ± 2.32 a

Different letters following the data in the same row indicate significant difference ($P < 0.05$, paired bootstrap test).

3.3 Life expectancy (e_{xj}) and reproductive value (v_{xj}) of *C. variegata* on four host plants

The age-stage life expectancy (e_{xj}) indicates the expected longevity of individual at age x and stage j after age x. The e_{xj} of a newly laid egg on *P. acerifolia*, *O. fragrans*, *A. julibrissin*, and *A. persica* was 281.48, 276.56, 265.40, and 281.56 d, respectively (Fig. 3). The e_{xj} of *C. variegata* females on *A. persica* exhibited a peak value of 22.15 d at 294 d of age, which was comparable to the corresponding peak values on *O. fragrans* (21.96 d), *P. acerifolia* (21.23 d), and *A. julibrissin* (18.44 d) at 280, 282, and 279 d of age, respectively (Fig. 3). The maximum e_{xj} value of *C. variegata* males on *P. acerifolia* (4.83 d at 285 d of age) was higher than those on *O. fragrans* (3.25 d), *A. julibrissin* (2.78 d), and *A. persica* (4.70 d) at 286, 284, and 289 d of age, respectively (Fig. 3).

The age-stage reproductive value (v_{xj}) is defined as the contribution of individuals of age x and stage j to the future population. The reproductive value (v_{xj}) of *C. variegata* at the pre-adult stage on *P. acerifolia* (1 440.64 eggs), *O. fragrans* (1 229.33 eggs), *A. julibrissin* (932.04 eggs), and *A. persica* (1 784.83 eggs) peaked at 281, 294, 278, and 319 d of age, respectively (Fig. 4). The v_{xj} value for adult females on *A. persica* (7 021.90 eggs) peaked at 295 d of age, and was higher than those of females on *P. acerifolia* (6 822.64 eggs), *O. fragrans* (6 628.23 eggs), and *A. julibrissin* (4 430.84 eggs), which peaked at 283, 281, and 280 d of age, respectively (Fig. 4).

4 DISCUSSION AND CONCLUSION

In our study, most eggs of *C. variegata* on *P. acerifolia*, *O. fragrans*, *A. julibrissin*, and *A. persica* hatched successfully and developed into adults. The hatching rates of eggs laid by adult females of *C. variegata* on *P. acerifolia* and *O. fragrans* were more than 50%, whereas those on *A. julibrissin* and *A. persica* exhibited an opposite trend. Collectively, the higher hatching rates of eggs and proportions of adult females of *C. variegata* on *P. acerifolia* and *O. fragrans* might result in more severe damage.

In a previous study, Zhang (2010) noted that *C. variegata* completes one generation in a year, and overwinters in the mature larval stage in northeastern and central China. Recently, Chen and Fan (2016) further found that *C. variegata* completed one generation per year in Shaanxi Province, China. Both these studies support that this pest produces only one generation per year in northern China. In our study, the pre-adult period of *C. variegata* on *P. acerifolia*, *O. fragrans*, *A. julibrissin*, and *A. persica* was 305.42, 305.07, 301.37, and 309.81 d, respectively, indicating that it could complete one generation per year, which is consistent with previous results.

The aim of garden designing is to build an aesthetically pleasing environment, by transforming natural and man-made landscapes and combining plants with architecture. Although gardens vary in size and complexity, they all include five essential

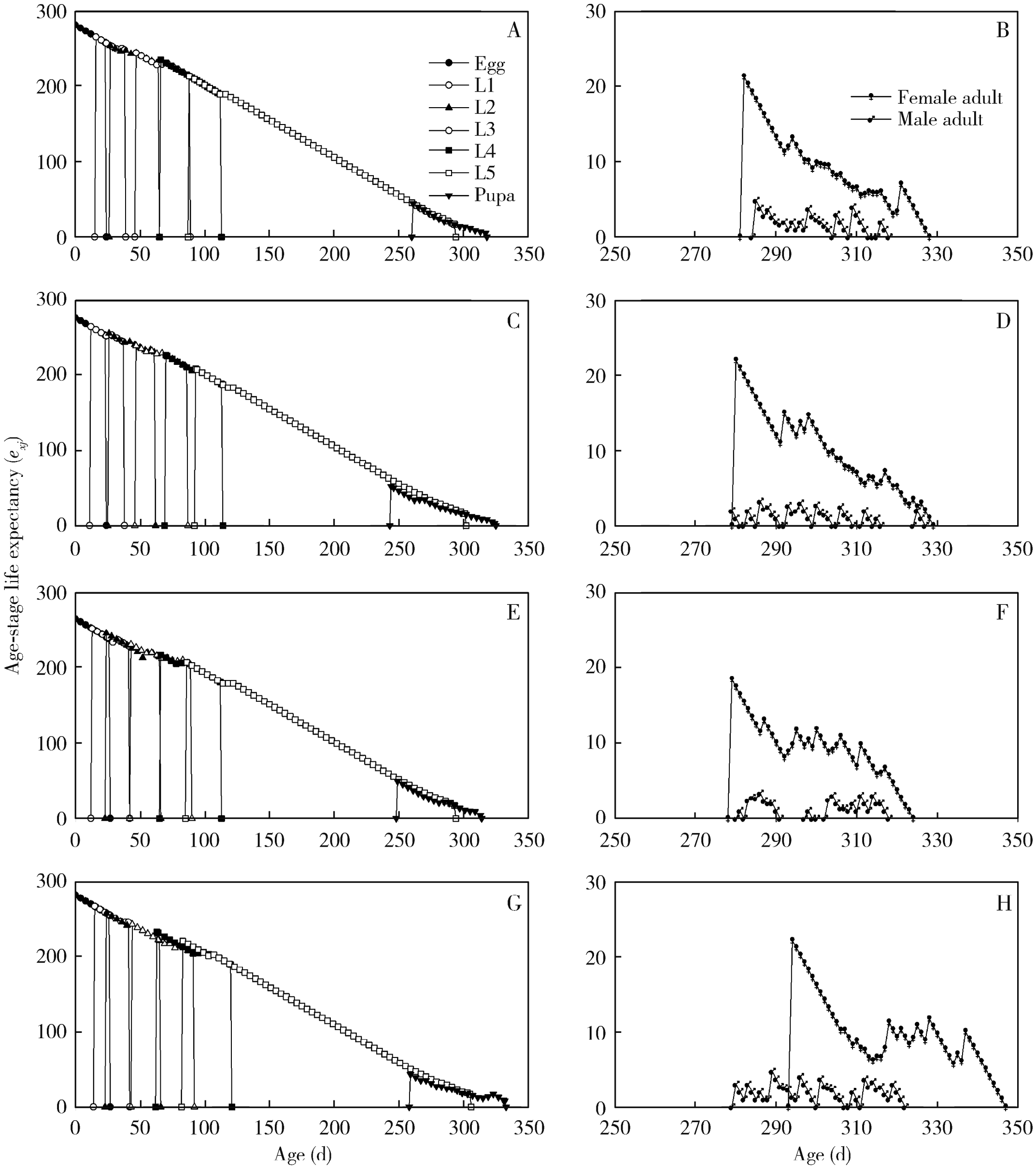

Fig. 3　Age-stage-specific life expectancy (e_{xj}) of *Clania variegata* on *Platanus acerifolia* (A and B), *Osmanthus fragrans* (C and D), *Albizia julibrissin* (E and F), and *Amygdalus persica* (G and H)
L1 – L5: 1st – 5th instar larva, respectively.

elements, *i. e.*, topography, plants, architecture, roads, and landscape sketches. Greening plants play important roles in embellishing the landscape. Most designers focus only on the aesthetic aspect of greening plants while designing a landscape, and neglect the control of severely damaging garden pests by these plants. Planting a single species over a large area can lead to outbreaks of targeted pests, resulting in serious damage (Chen *et al.*, 2018). Mixed cropping and inter-planting of crops can improve the resistance of the crop population, and naturally control plant diseases and insect pests (Shen *et al.*, 2007). We observed a significantly higher intrinsic rate of increase (r) of *C. variegata* on *P. acerifolia* than on *O. fragrans*, *A. julibrissin*, and *A. persica* (Table 2). We recommend planting these species alternately while designing gardens and parks.

The age-stage-specific life expectancy (e_{xj}), representing the life expectancy of individuals at age x and stage j (Gabre *et al.*, 2005), of *C. variegata* is illustrated in Fig. 3. The life expectancy of a newly laid egg on *P. acerifolia*, *O. fragrans*, *A. julibrissin*, and *A. persica* was 281.48, 276.56, 265.40, and 281.56 d, respectively, and it decreased with increasing age. The reproductive value (v_{xj}) indicates the expected number of offspring produced by individuals of age x and stage j

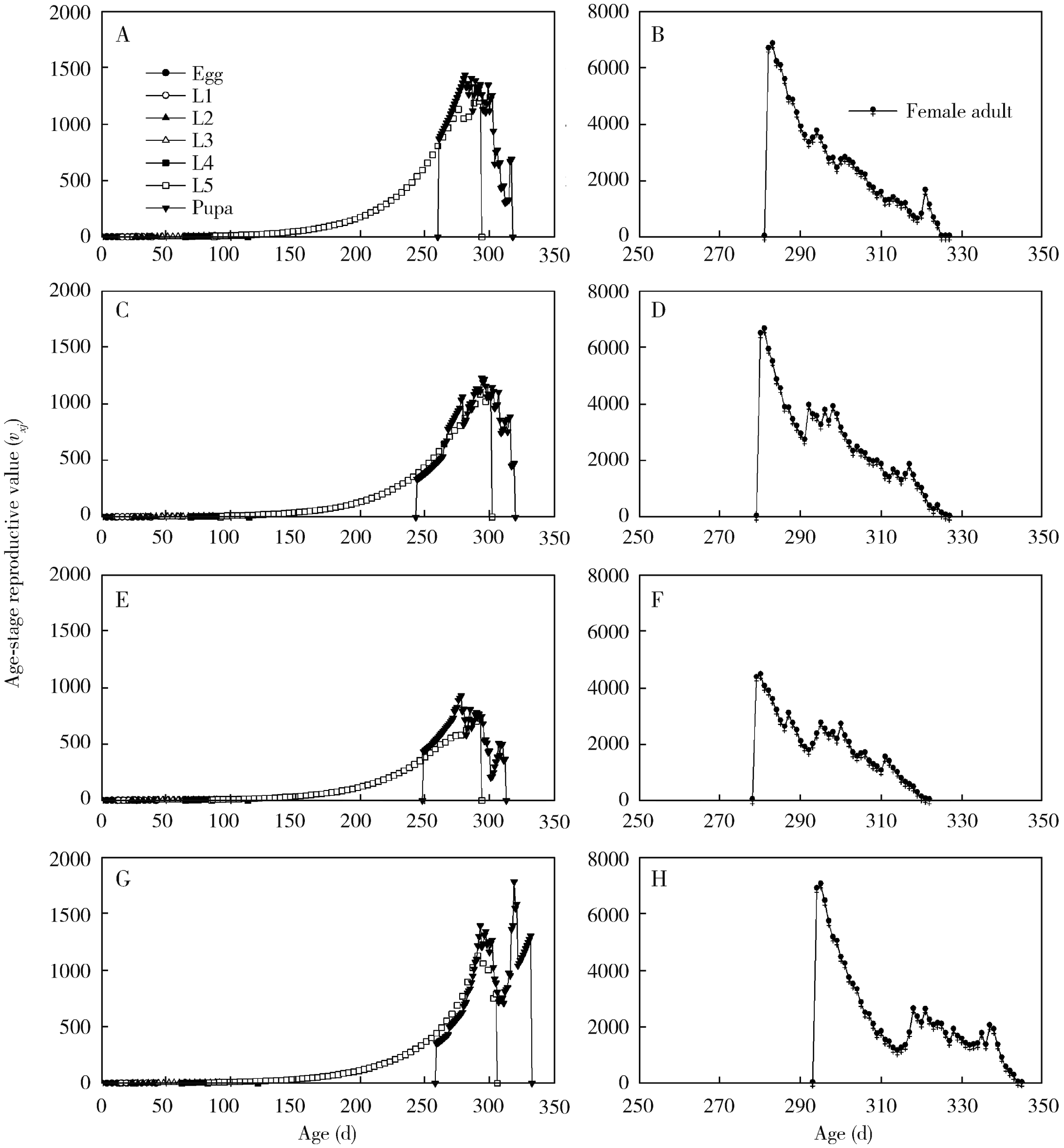

Fig. 4 Age-stage-specific reproductive value (v_{xj}) of *Clania variegata* on *Platanus acerifolia* (A and B), *Osmanthus fragrans* (C and D), *Albizia julibrissin* (E and F), and *Amygdalus persica* (G and H)
L1 – L5: 1st – 5th instar larva, respectively.

(Fisher, 1930; Pianka, 1994; Gabre *et al*., 2005), and the reproductive value of a new egg (v_{01}) represents the finite rate of increase (λ). The reproductive values on *P. acerifolia*, *O. fragrans*, *A. julibrissin*, and *A. persica* peaked at 283, 281, 280, and 295 d of age, respectively. This implies that, compared to other ages, female individuals aged 283, 281, 280, and 295 d contribute the most to the population.

In conclusion, the intrinsic rate of increase (r) of *C. variegata* on *P. acerifolia* was significantly higher than those on *O. fragrans*, *A. julibrissin* and *A. persica*, indicating that the host plant species can significantly influence the reproductive potential of this herbivorous insect. Our results provide a scientific basis for developing effective control measures against *C. variegata* by planting selected green trees during landscape design. However, only four host plants were assessed in this study, and more host plants should be included in future studies.

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园林害虫大袋蛾在四种寄主植物上的繁殖潜能评估

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摘要：【目的】大袋蛾 *Clania variegata* 是一种严重危害多种植物的食叶性害虫。为了通过合理配植园林植物防治大袋蛾，本研究评估了在悬铃木、月桂、合欢及桃树4种寄主植物上大袋蛾的繁殖潜能。【方法】2018年7月15日至2019年6月21日，在室外纱网隔离环境中测定了大袋蛾分别在悬铃木、月桂、合欢和桃树上的卵期、幼虫期、蛹期、存活率、成虫寿命、雌成虫产卵期和每日单雌产卵量。采用年龄-龄期两性生命表程序TWOSEX-MSChart对大袋蛾发育历期、存活率、成虫寿命及雌虫繁殖力数据进行了分析。【结果】寄主植物种类可显著影响大袋蛾的发育历期和成虫寿命。取食月桂时，大袋蛾2，3，4和5龄幼虫的历期显著长于取食其他植物时的；取食桃树时，大袋蛾雌成虫寿命(11.47 d)显著长于取食月桂时的(10.26 d)。大袋蛾取食月桂时的产卵期(7.04 d)显著短于取食悬铃木(7.52 d)、合欢(7.59 d)及桃树(8.11 d)时的。大袋蛾取食悬铃木时的净繁殖力(R_0)(2 015.70 粒卵)显著高于取食月桂(1 419.12 粒卵)、桃树(1 289.66 粒卵)和合欢(976.67 粒卵)时的。大袋蛾取食悬铃木时的内禀增长率(r)(0.02523/d)显著高于取食月桂(0.02377/d)、合欢(0.02304/d)及桃树(0.02194/d)时的。【结论】大袋蛾取食悬铃木时的繁殖潜能显著高于取食月桂、合欢及桃树时的，在园林设计中合理间隔种植月桂、合欢及桃树可能有利于减少大袋蛾对非嗜食植物的危害。

关键词：大袋蛾；悬铃木；月桂；合欢；桃树；繁殖潜能；繁殖力

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